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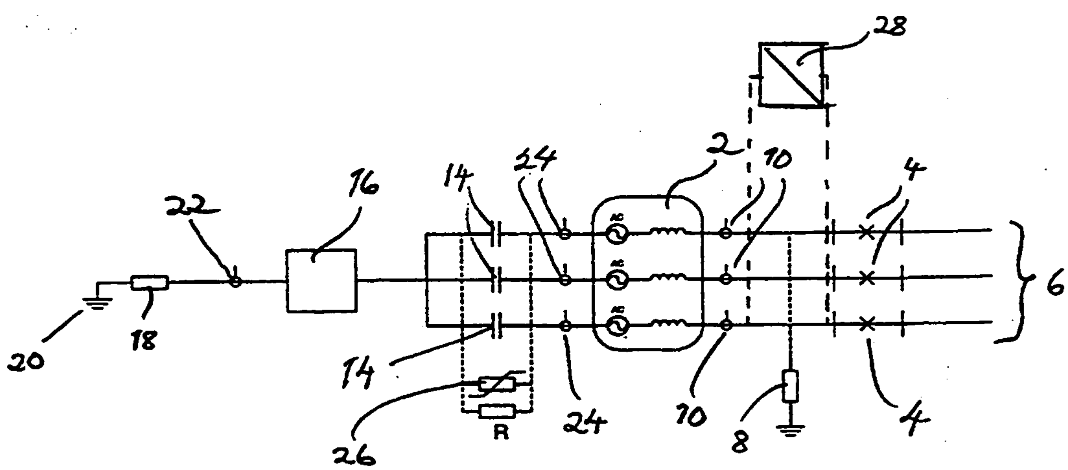
(54) Title: SERIES COMPENSATION OF ELECTRIC ALTERNATING CURRENT MACHINES



(57) Abstract

In a method of series compensating rotating electric alternating current machines (2) connected, directly or via a static current converter (28), to a three-phase distribution or transmission network (6), wherein the stator winding of the alternating current machine is Y-connected, a capacitive circuit (14) for the fundamental frequency of the voltage is connected in each phase between the down side of the winding and the earth point (20) of the distribution or transmission network (6). A device for such series compensation comprises a capacitive circuit (14) for the fundamental frequency of the voltage, connected between the down side of the winding and the earth point (20) of the distribution or transmission network (6).

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SERIES COMPENSATION OF ELECTRIC ALTERNATING CURRENT MACHINES

The present invention relates to a method and a device for series compensating a rotating electric alternating current machine connected, directly or via a static current converter, to a three-phase distribution or transmission network, wherein the stator winding of the alternating current machine is Y-connected. The invention also relates to a rotating electric machine provided with such a series compensation device.

The invention refers primarily to electric alternating current machines intended for use as generators in power stations for generating electric power. A typical operating range may be 36 to 800 kV, so that they can be connected directly to all types of high-voltage power networks. This is possible thanks to the use of high-voltage insulated electric conductors with solid insulation similar to cables for transmitting electric power, in the following termed high-voltage cable. The cable is also provided with an outer semiconducting layer with the help of which its potential in relation to the surroundings is defined.

A conductor is known through US 5,036,165, in which the insulation is provided with an inner and an outer layer of semiconducting pyrolized glassfiber. It is also known to provide conductors in a dynamo-electric machine with such an insulation, as described in US 5 066 881 for instance, where a semiconducting pyrolized glassfiber layer is in contact with the two parallel rods forming the conductor, and the insulation

in the stator slots is surrounded by an outer layer of semiconducting pyrolized glassfiber. The pyrolized glassfiber material is described as suitable since it retains its resistivity even after the impregnation treatment.

Series compensation on both high voltage transmission networks and distribution networks is already known.

Series compensation on both high voltage transmission networks and distribution networks is already knwn. It is also well known that geomagnetically induced currents can cause harmful heating in directly grounded power network system

From US, A1, 4,341,989 a device is also previously known for phase compensation of a multiphase rotating electric alternating current machine by connecting in series or in parallel with each phase winding a capacitive element on the upside of the winding.

The object of the present invention is to provide a new method and a new device for lowering the system reactance through series compensation of the alternating current machine in question as well as for preventing geomagnetically induced currents.

This object is achieved with a method and a device of the type described in the introduction, having the features defined in claim 1 and claim 2, respectively.

According to the invention, thus, the compensation is performed on the down side of the windings, so that

low-voltage insulated capacitors can be used, which is not possible with series compensation in high-voltage transmission networks according to known technology. Less expensive capacitors can therefore be used in the device according to the invention, since they are protected by the machine itself and connected to the neutral point, which is at low potential in relation to earth. This solution is especially advantageous for the type of machines to which the present invention relates, since their upside is intended to be connected directly to high-voltage power networks.

According to an advantageous embodiment of the device according to invention, an over-voltage protection means is connected in parallel with the capacitors so that they are protected from any over-voltages that may appear in the event of a fault condition.

According to a second advantageous embodiment of the device according to the invention, a bandstop filter is arranged between the Y-point of the capacitor bank formed by the capacitors and the earth point of the distribution or transmission network, possibly with a low-ohmic resistor connected between the bandstop filter and the earth point. This resistor may be a neutral-point resistor, dimensioned for a harmless earth-fault current of a few tens of amperes. An earth fault in the alternating current machine or the generator is able to emit an earth-fault current via this resistor but, by controlling the earth-fault current, measures can be taken to disconnect the generator or possibly the faulty phase.

From a power network point of view any increase in transient machine reactance can also be efficiently compensated in this manner.

In the machine according to the invention the windings are preferably composed of cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such cables are flexible, which is an important property in this context since the technology for the machine according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature of the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

Windings in the present invention are constructed to retain their properties even when they are bent and when they are subjected to thermal stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers

consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions

required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber, butyl graft polyethylene, ethylene-butyl-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks or other damage appear and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently large to contain

the electrical field in the cable, but sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

To explain the invention more clearly an embodiment of the device according to the invention will be described in more detail by way of example, with reference to the accompanying drawings in which Figure 1 shows an embodiment of the device according to the invention and Figure 2 shows a cross section through the high-voltage cable used in the rotating electric machine according to the invention.

Figure 1 shows an alternating current machine 2 in the form of a generator, the phase voltages of which are connectedly directly to the network 6 via isolators and breakers 4. Over-voltage protection means 8 and current measuring devices 10 are also provided on the output side of the generator 2.

The stator winding of the generator 2 is Y-connected and a series-compensation capacitor 14 is connected in each of the phases on the down side of the winding. A

bandstop filter 16 is connected to the Y-point of the capacitor bank and a neutral-point resistor 18 is connected to the earth point 20 of the network 6. Current measuring devices 22, 24 are also provided on this side of the generator 2.

Connecting a series capacitor 14 in each of the phases achieves series compensation of the alternating current machine 2, thereby lowering the system reactance.

Over-voltage protection means 26 and a resistance R are suitably provided in order to protect the capacitors 14 in the event of a fault condition.

The filter 16 has nothing directly to do with the invention and will not be described in more detail.

The neutral-point resistor 18 is dimensioned to limit earth faults to a harmless magnitude of a few tens of amperes. An earth fault in the generator 2 may thus result in an earth-fault current through the resistor 18, and controlling the magnitude of this current enables measures to be taken for disconnecting the generator and possibly the faulty phase.

Alternatively the generator 2 may be connected to the network via a converter 28, as indicated in Figure 1.

The field excitation of the generator has been omitted in Figure 1.

Figure 2 shows a cross section through a high-voltage cable 29 used in the rotating electric machine

according to the invention. The high-voltage cable 29 is composed of a number of strand parts 31 made of copper, for instance, and having circular cross section. These strand parts 31 are arranged in the middle of the high-voltage cable 29. Around the strand parts 31 is a first semiconducting layer 32. Around the first semiconducting layer 32 is an insulating layer 33, e.g. XLPE-insulation, and around the insulating layer 33 is a second semiconducting layer 34.

CLAIMS

1. A method of series compensating rotating electric alternating current machines (2) connected, directly or via a static current converter (28), to a three-phase distribution or transmission network (6), wherein the stator winding of the alternating current machine is Y-connected, **characterized** in that a capacitive circuit (14) for the fundamental frequency of the voltage is connected in each phase between the down side of the winding and the earth point (20) of the distribution or transmission network (6).

2. A device for series compensating rotating electric alternating current machines (2) connected, directly or via a static current converter (28), to a three-phase distribution or transmission network (6), wherein the stator winding of the alternating current machine is Y-connected, **characterized** in that a capacitive circuit (14) for the fundamental frequency of the voltage is connected in each phase between the down side of the winding and the earth point (20) of the distribution or transmission network (6).

3. A device as claimed in claim 2, **characterized** in that each capacitive circuit includes a capacitor (14).

4. A device as claimed in claim 3, **characterized** in that an over-voltage protection means (26) is connected in parallel with the capacitors (14).

5. A device as claimed in any of claims 2-4, **characterized** in that a bandstop filter (16) is arranged between the Y-point of the capacitor bank formed by the capacitors (14), and the earth point (20) of the distribution or transmission network (6).

6. A device as claimed in claim 5, **characterized** in that a low-ohmic resistor (18) is connected between the bandstop filter (16) and the earth point (20) of the distribution or transmission network (6).

7. A rotating electric machine having windings drawn in slots in the stator, **characterized** in that the windings are wound using high-voltage cable and in that the machine is provided with a device as claimed in any of claims 2-6.

8. A machine as claimed in claim 7, **characterized** in that the high-voltage cable is of a type comprises a core having a plurality of strand parts, an inner semiconducting layer surrounding the core, an insulating layer surrounding the inner semiconducting layer, and an outer semiconducting layer surrounding the insulating layer.

9. A machine as claimed in claim 8, **characterized** in that the high-voltage cable has a diameter within the interval of 20-200 mm and a conducting area within the interval of 80-3000 mm^2.

10. A machine as claimed in any of claims 7-9, **characterized** in that the cable is flexible and the layers abut one another.

11. A machine as claimed in any of claims 7-10, **characterized** in that said layers are of materials having such elasticity and such coefficients of thermal expansion that the changes in volume in the layers caused by temperature fluctuations during operation are absorbed by the elasticity of the materials, the layers thus retaining their adhesion to each other upon the temperature fluctuations that occur during operation.

12. A machine as claimed in any of claims 7-11, **characterized** in that the materials in said layers have high elasticity, preferably with a modulus of elasticity less than 500 MPa, preferably less than 200 MPa.

13. A machine as claimed in any of claims 7-12, **characterized** in that the coefficients of thermal expansion for the materials in said layers are substantially the same.

14. A machine as claimed in any of claims 7-13, **characterized** in that the adhesion between layers is of at least the same magnitude as the strength of the weakest of the materials.

15. A machine as claimed in any of claims 7-14, **characterized** in that each of the semiconducting layers essentially constitutes one equipotential surface.

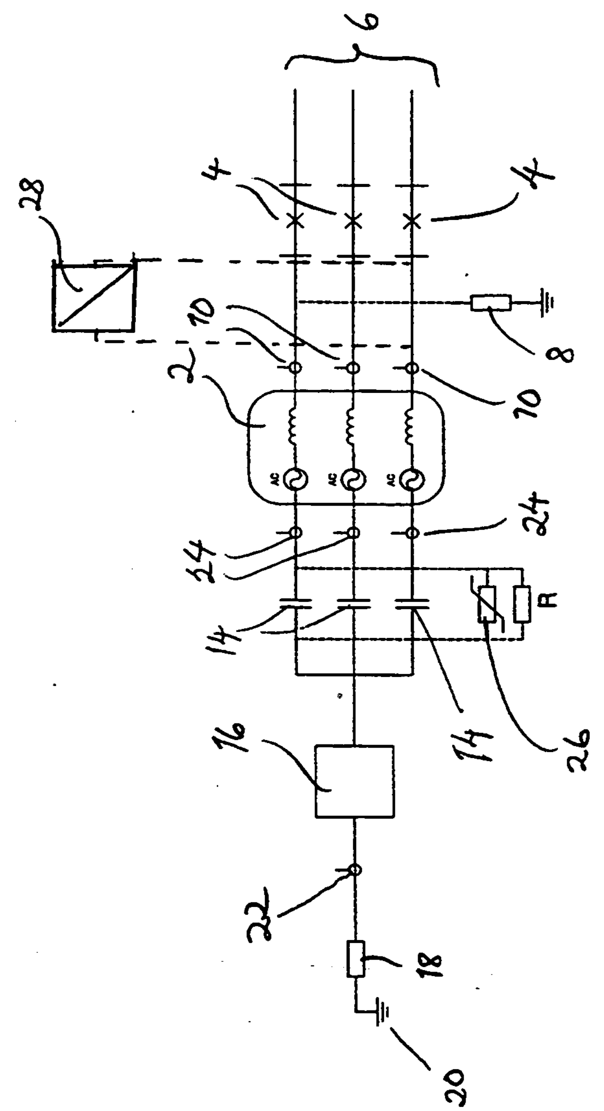

Fig. 1

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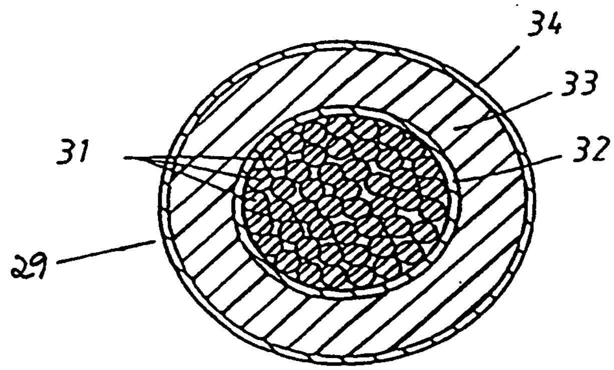

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/00162

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02J 3/18, H02K 11/00, H02K 3/30, H02K 3/40
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02J, H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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International application No.
PCT/SE 98/00162

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

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